RESEARCH ARTICLE

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Fabrication and Dosimetric Characteristics of Silicon Elastomer-Based Bolus Using External Beam Radiotherapy

M Boopathi[1,2], D Khanna[1], P Venkatraman[3]*, R Varshini[3], C S Sureka[4], S Pooja[4]

Abstract

Objective: A study on dosimetric characteristics of silicon elastomer-based bolus was carried out using a Linear accelerator (Varian – Unique Performance). The study is performed to know if the silicone elastomer based bolus can be used in the radiotherapy. A bolus is a tissue equivalent material used to provide uniform dose to the uneven surface contours. It is exposed during the radiation therapy and also provides maximum dose (dmax) to treat surface tumors in case of high energy photons like megavoltage therapy photons. It is used in the case of external beam radiation therapy. **Methods:** In this study, the bolus was fabricated using PDMS substrate with a curing agent by the ratio of 10:1. The bolus was fabricated in two thicknesses 0.5cm and 1cm. The dosimetric characteristics like transmission factor, mass attenuation coefficient, durability, homogeneity, density test of the fabricated bolus were studied. **Results:** The dosimetric characteristics of the silicone elastomer based bolus were studied over a period of one month by exposing it in a 6MV photon. The result of the study shows that the silicone elastomer based bolus fabricated, satisfies the dosimetric characteristics needed for a tissue equivalent bolus to be used in the radiation therapy. **Conclusions:** The fabricated bolus could increase the percentage surface dose, reduce skin-sparing effect, and protect OAR. The aim of this is to provide an adjustable, transparent, and easily fabricated, less expensive, nontoxic bolus which can be used in the radiotherapy.

Keywords: Silicon elastomer- external beam radiotherapy- bolus

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Introduction

Medicine department seems to be developed dynamically in the 21st century, but still there are some areas that lack efficient solutions when it comes to fighting the diseases. One of such diseases, which cause millions of people to suffer is cancer. Treatment for cancer varies for different types. One of such treatments, which is commonly used, is radiotherapy. It has the principle of killing the tumors and cancer cells without affecting normal healthy tissues (Babic et al., 2002; Banaee N et al., 2013; Benoit et al., 2009; Butson MJ et al., 2000; Dubois et al., 1996; Khan, 1984; Radiation oncology physics: A handbook for teachers and students. 2nd ed. Vienna: International Atomic Energy Agency, 2005; Richmond et al., 2016; Walker et al., 2005) .

Linear accelerator (LINAC) is the machine used in external beam radiotherapy which has the capacity of producing high energy electrons and photons. In photon and electron therapy, to spare the normal tissues and to treat tumors in an efficient way, beam modifiers like compensators, wedge filters, bolus, breast cone, penumbra trimmers, MLCs, custom blocks etc. are used. Beam modifiers are used to provide alteration in the spatial distribution of radiation within the patient, by insertion of any material in the beam path.

The compensation tissue that is used in photon and electron therapy is called a Bolus, which can be used in direct contact with the patient's surface. The characteristics of a good bolus include, non-toxicity, non-sticky, have good visibility, and should have the computed tomotherapy (CT) number between 130 and 160 HU (Apipunyasopon et al., 2020). A Bolus should be a material, which is equivalent to body tissue, so that it can be used as a tissue compensator. It is used to even out the surface contour in case of kilovoltage radiation. In megavoltage radiation, bolus is used to bring the buildup zone near the skin for treatment of superficial tumors. The thickness of the bolus used varies according to the energy of the radiation. Commonly used bolus materials are Cotton soaked with water, Paraffin wax. The commercially available bolus: Super flab (it is a thick bolus and doesn't undergo elastic deformation. It is made of synthetic oil gel), Super stuff (it is prepared by adding

[1]Department of Applied Physics, Karunya Institute of Technology and Sciences, Coimbatore, India. [2]Dharan Cancer Speciality Centre Pvt Ltd, Salem, India. [3]Department of Medical Physics, Bharathidasan University, Tiruchirappalli, Tamilnadu, India. [4]Department of Medical Physics, Bharathiar University, Coimbatore, Tamilnadu, India. *For Correspondence: logupathi@gmail.com, venkat00108@gmail.com

water to a powder to get a pliable gelatin like material), and Bolx sheets (gel enclosed in plastic sheet) (Agrawal et al., 2022; Apipunyasopon et al., 2020; Kapoor et al., 2020; Mehta et al., 2022).

In this study, silicon elastomer was used as a primary material for synthesizing bolus. An elastomer is a polymer which has high viscosity and elasticity. Silicone elastomer has the following benefits, Extreme temperature resistance (+230degree Celsius to -60degree Celsius), Excellent environment resistance (UV, general weather like rain, snow, frost), Low compression set (resistance to compression at high temperature), Low level of flammable components (when exposed to flame, elastomer reduces to silica ash), High physiological inertness (tasteless, odorless, nontoxic, resistance to bacteria and fungi) considering these benefits, silicone elastomer has been used for the study.

Material and Methods

Bolus Fabrication

A solution of the Polydimethylsiloxane (PDMS) monomer and the curing agent (10:1) was degassed for 30 min under vacuum and poured into a petri dish to a thickness of 1 and 2 mm. After polymerization at 80°C for 3 hrs, the thicken substrates were cut into pieces measuring 10 mm × 20 mm. To bring about the wrinkles, the prepared PDMS substrates were made fast in a customized be elastic apparatus. Each PDMS substrate was then extended to 130% of its original length and treated with oxygen plasma for 3 min under a pressure of 10 mTorr using a plasma system. The stiff layer formed by PDMS substrate was then relaxed to the original length and placed on a glass slide for the experiments shown in figure 1. Density test, dosimetry test, transmission factor, conformability, repeatability, and transparency were analysed in order to verify the performance of silicone elastomer based bolus.

Density Test

The measured density of a material is equal to its mass of the material divided by its volume. The fabricated bolus weight is measured using a digital scale, whereas the volume of the bolus is calculated using its dimensions. So that the silicone elastomer based bolus density can be calculated using equation as follows (Hariyanto AP et al., 2020):

$$\rho = m/v \qquad (1)$$

with ρ is the mass of the material and m is mass (kg), and V is the material volume (m3)

Dosimetry Test

In this test, the sample will be irradiated Photons with energies 6 MV using Linear Accelerator (Varian Unique). Radiation is done by setting the phantom source to surface distance (SSD) of 90cm, 100 cm, and 110 cm the radiation area of 5 x 5 cm^2, 10 × 10 cm^2, and the dose rate of 100 MU/min. Ionizing charge measurements, using Farmer type chamber 0.6 cm^3 for irradiation with photons. Every irradiation, the detector is placed at the Dmax that depends on the energy used. Furthermore, the phantom water slab is irradiated with a set up that has been determined as shown in Figure 2. (a). Next, on the surface of the phantom water slab, a bolus is placed and irradiated with a predetermined set up as seen in Figure 2.(b) using bolus with SSD 100cm and, (c) experimental setup. Various thicknesses (was 0.5 and 1 cm) of the silicone elastomer bolus was used for output measurement

Transmission Factor

Transmission factor of the silicone elastomer based bolus is defined as the ratio of the meter readings obtained at a depth of with silicone elastomer bolus to that obtained in the without of the silicone elastomer bolus.

$$\text{Transmission factor} = \frac{\text{With Bolus}}{\text{Without Bolus}} \qquad (2)$$

The bolus was measured using a phantom water slab. Initially, we set the different SSD (90cm, 100cm, and 110cm) at the surface of the phantom water slab, and then the sample was placed over the phantom water slab. The transmission factors were measured at 6MV Photon energy using Farmer type chamber 0.6 cm^3 with the different field size of 5×5cm2 and 10×10 cm^2 at the surface of the slab phantom and positioned in the Dmax of 1.5cm respectively. The attenuation coefficient was determined by collection of ion charge at different monitor units 100 MU – 500MU. Further, the 0.5 and 1 cm thickness of silicone elastomer bolus used for analysis on transmission factor.

Repeatability and Reproducibility

The repeatability for the silicone elastomer bolus was analyzed day by day for a period of one month. The reproducibility of charge collection is a measurement of results that can be attained by various researches, based on the same methods. After each measurement the bolus should be washed with the ethanol solution as the bolus is used for different patients such as awaiting the moisture.

Effective mass attenuation coefficients

The particle beam of mono energetic photons with an incident intensity Io, penetrating a layer of material with mass thickness x and density ρ, emerges with intensity I given by the exponential attenuation. When using the mass attenuation coefficient, the Beer-Lambert law is written in alternative form as (Hariyanto AP et al., 2020)

$$I\backslash Io = \exp [- (\mu/\rho)\, x] \qquad (3)$$

$$(\mu/\rho) = x^{-1} \text{ in } (Io/I)$$

Where

μ is the attenuation coefficient;

ρ_t is obtained by multiplying the thickness t by the density $x = \rho_t$

Io is obtained from measured value without bolus

I is obtained from measured value with bolus

Results

The present study, silicone elastomer based bolus has been successfully prepared as a tissue equivalent compensation for radiotherapy which is shown in Figure 3. The silicone elastomer based bolus has a transparent, oily nature, visibility and has similar characteristics with soft tissue.

Density of silicone elastomer based Bolus

The results of density measurements for 0.5 and 1 cm thickness of silicone elastomer bolus variations shown in figure 3. That as the silicone elastomer bolus thickness increases; the density range will also decrease. Because, the density range is proportional to the volume of the silicone elastomer bolus. The density measurement was also taken having range of 0. 965g/m³and 0.967g/m³Which is density equivalent to fat, tissue or water, and air with their respectively of 0.91 g/cm³, 1 g/cm³ and 1.29g/cm³.

Dosimetry Test (Transmission factor and mass attenuation coefficients)

In this study, a dosimetry test was carried out by exposing the bolus with 6 MV, as the test was completed to determine bolus characteristics such as transmission factor and effective mass attenuation coefficients. This study was calculated the transmission factors can be obtained from comparing with bolus and without bolus. Those results can be calculated and performed as shown in Tables 1 and 2.

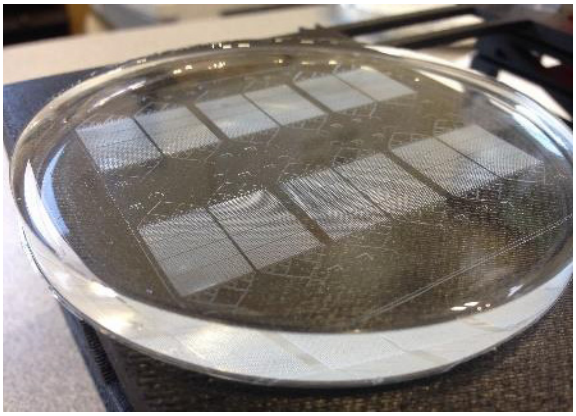

Figure 1. PDMS Formed in the Petri Dish – Final Form of Silicone Elastomer based Bolus

Based on the Tables 1 and 2 show the transmission factor results obtained from 6 MV, silicone elastomer bolus with the thickness of 0.5 cm and 1 cm have a transmission factor of less than 1. In this condition the bolus can reduce the intensity of the photons from the original intensity.

In this study, a dosimetry test was carried out by exposing the bolus with 6 MV photons, and the test was completed to determine bolus characteristics such as effective mass attenuation coefficients. Mass attenuation coefficient is important characteristics needed for an attenuating material to be used during the therapy. It is required to determine the penetration of x and gamma ray in a matter. This study calculates the effective mass attenuation coefficients, which can be obtained from formula 3. Those results can be calculated and performed as shown in Tables 3 and 4.

The determination of the effective mass attenuation coefficient was chosen because of the process of interaction with irradiation of megavoltage photons results obtained from 6 MV, silicone elastomer bolus with the thickness of 0.5 cm and 1 cm show in Tables 3 and 4. The calculated mass attenuation coefficient of the bolus mass of 0.5 to 1 cm in thickness with energy increases the attenuation coefficient.

Durability of bolus over time

Durability of a material is the ability to remain undamaged over a period of time in the surrounding environment. It is important for a material to be durable for reducing the expense. Over the period of one month the material remained undamaged and the measurements were reproducible with minimum standard deviation of 0.0003%. The bolus was examined physically for wear and tear damages and also the meter reading was taken

Table 1. Transmission Factors of Boluses for Photon Energy 6 MV with Radiation area 5 × 5 cm^2 at Different Monitor Unit

Monitor Unit		Without Bolus	With Bolus	Trans. Factor	Without Bolus	With Bolus	Trans. Factor	Without Bolus	With Bolus	Trans. Factor
		Depth 90 cm			Depth 100 cm			Depth 110 cm		
		Dose nC								
100 MU/min	0.5 cm	18.69	18.42	0.9855	15.17	14.98	0.9875	12.55	12.34	0.9833
	1 cm	18.25	18.03	0.9879	14.92	14.56	0.9759	12.19	12.01	0.9852
200 MU/min	0.5 cm	37.45	37.31	0.9963	30.54	30.25	0.9905	25.43	25.05	0.985
	1 cm	37.13	37.01	0.9967	30.19	30	0.9937	25.17	24.92	0.99
300 MU/min	0.5 cm	56.11	55.92	0.9966	45.87	45.33	0.9882	37.68	37.56	0.9968
	1 cm	55.83	55.61	0.9961	45.41	45.04	0.9918	37.23	37.02	0.9944
400 MU/min	0.5 cm	74.93	74.5	0.9943	60.86	60.41	0.9926	50.34	50.09	0.995
	1 cm	74.53	74.16	0.995	60.34	60.11	0.9962	50.02	49.89	0.9974
500 MU/min	0.5 cm	93.42	93.09	0.9965	75.91	75.45	0.9939	62.93	62.66	0.9957
	1 cm	93.12	92.86	0.9972	75.53	75.11	0.9944	62.53	62.31	0.9965

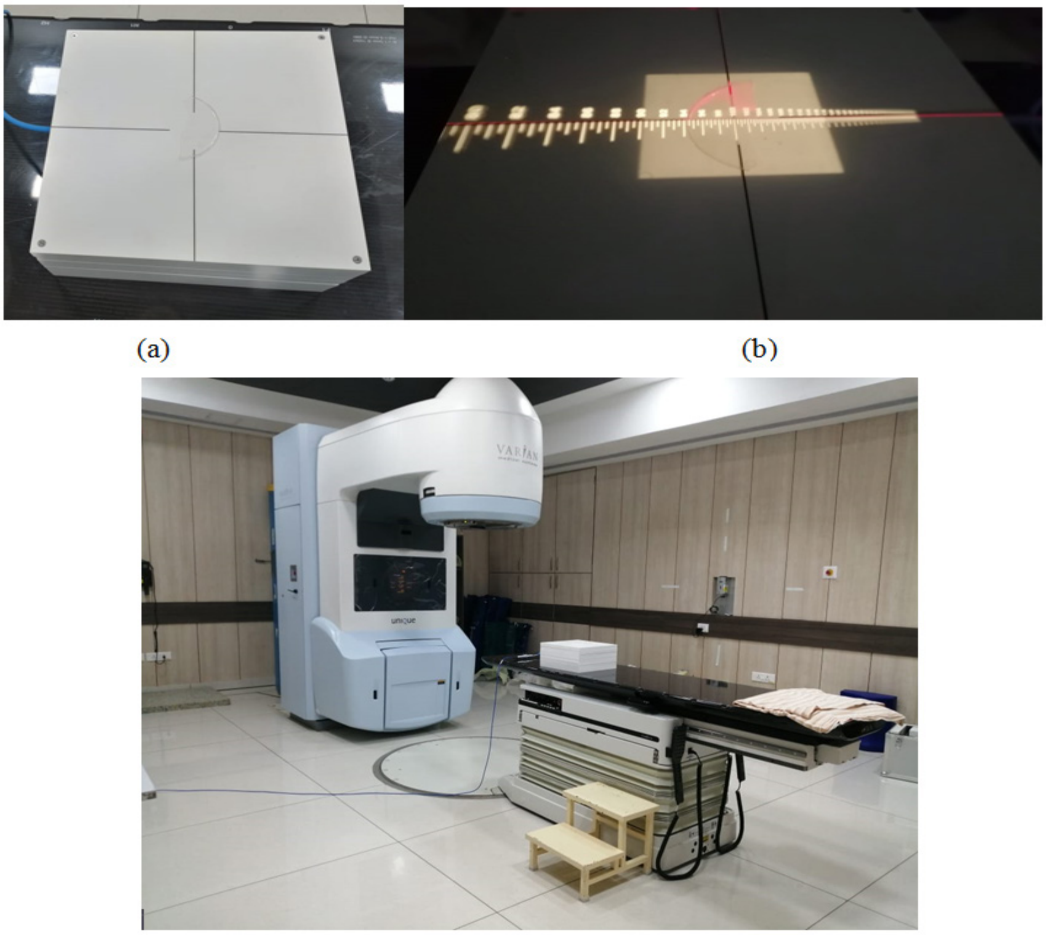

Figure 2. Schematic Diagram of the Study. (a), surface of the phantom water slab with a bolus; (b), using bolus with SSD 100cm; (c), experimental setup.

by keeping the bolus in beams path and reading were analyzed. The measured electrometer values were taken over a period of a month as shown in Figure 4. The figure represents constant values for the period of one month.

Homogeneity

The homogeneity of the material refers to the uniformity throughout the material. Homogeneity of the bolus is required to provide uniform dose to the surface of the patient. The homogeneity of silicone elastomer bolus is represented in a graph below. Figure 5 indicates that small variation in the stability and the standard deviation is estimated at 0.0002%.

Table 2. Transmission Factors of Boluses for Photon Energy 6 MV with Radiation Area 10 × 10 cm^2 at Different Monitor Unit

Monitor Unit		Without Bolus	With Bolus	Trans. Factor	Without Bolus	With Bolus	Trans. Factor	Without Bolus	With Bolus	Trans. Factor
		Depth 90 cm			Depth 100 cm			Depth 110 cm		
					Dose nC					
100 MU/min	0.5 cm	20.11	19.76	0.9826	16.3	16.02	0.9828	13.47	13.23	0.9822
	1 cm	19.89	19.51	0.9809	16.01	15.83	0.9887	13.13	13	0.99
200 MU/min	0.5 cm	40.36	40.12	0.9941	32.86	32.5	0.989	27.09	26.89	0.9926
	1 cm	40.06	39.99	0.9983	32.46	32.24	0.9932	26.83	26.61	0.9918
300 MU/min	0.5 cm	60.41	60.14	0.9955	48.91	48.67	0.9951	40.58	40.33	0.9938
	1 cm	60.17	59.9	0.9955	48.73	48.35	0.9922	40.38	40.08	0.9926
400 MU/min	0.5 cm	80.63	80.13	0.9938	65.16	64.86	0.9954	54.03	53.78	0.9954
	1 cm	80.34	79.91	0.9946	64.91	64.51	0.9938	53.81	53.49	0.994
500 MU/min	0.5 cm	100.4	100.1	0.997	81.21	80.98	0.9972	67.61	67.26	0.9948
	1 cm	100.09	99.82	0.9973	81	80.63	0.9954	67.37	67.01	0.9945

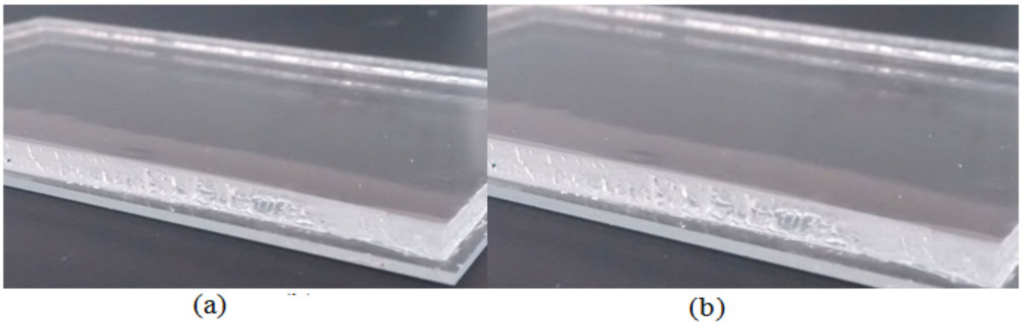

Figure 3. The Synthesized Silicone Elastomer Bolus with Varies Thickness a) 0.5 cm, and b) 1 cm

Discussion

This work propagates the dosimetric characteristics of silicon elastomer-based bolus for two boluses of thickness 0.5 cm and 1 cm. The information of bolus density was 0.965 and 0.967 g/cm^3 for 0.5 and 1cm boluses respectively, from a density test which was carried out gave the similarity to the tissue density. In this study the

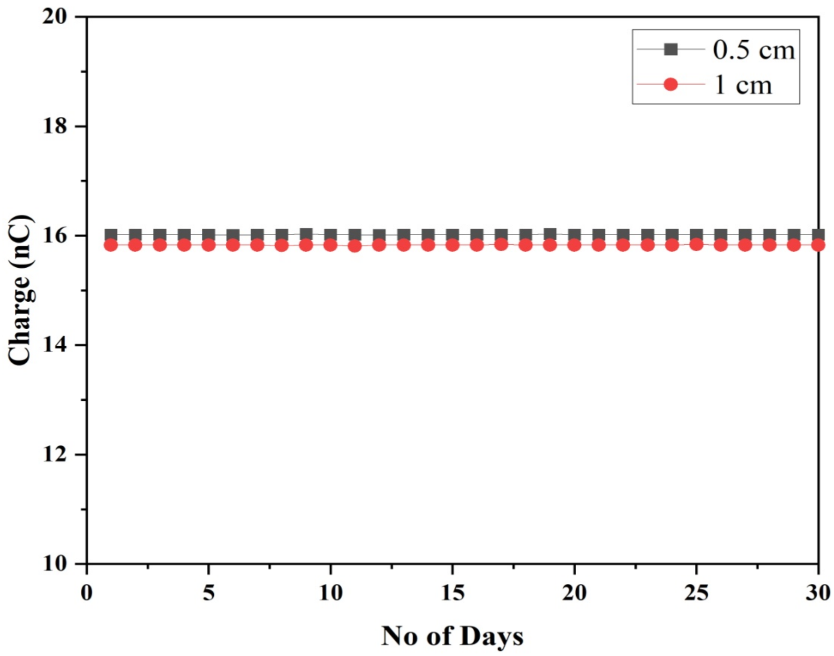

Figure 4. Durability of Silicone Elastomer Bolus Over a Period of One Month

Table 3. Mass Attenuation co Efficient (MAQ) of Boluses for Photon Energy 6 MV with Radiation area 5 × 5 cm^2 at Different Monitor Unit

Monitor Unit		Without Bolus	With Bolus	MAQ	Without Bolus	With Bolus	MAQ	Without Bolus	With Bolus	MAQ
		Depth 90 cm			Depth 100 cm			Depth 110 cm		
					Dose nC					
100 MU/min	0.5 cm	18.69	18.42	0.0075	15.17	14.98	0.0065	12.55	12.34	0.0087
	1 cm	18.25	18.03	0.0125	14.92	14.56	0.0252	12.19	12.01	0.0153
200 MU/min	0.5 cm	37.45	37.31	0.0019	30.54	30.25	0.0049	25.43	25.05	0.0078
	1 cm	37.13	37.01	0.0033	30.19	30	0.0065	25.17	24.92	0.0103
300 MU/min	0.5 cm	56.11	55.92	0.0046	45.87	45.33	0.0061	37.68	37.56	0.0016
	1 cm	55.83	55.61	0.004	45.41	45.04	0.0084	37.23	37.02	0.0058
400 MU/min	0.5 cm	74.93	74.5	0.0029	60.86	60.41	0.0038	50.34	50.09	0.0046
	1 cm	74.53	74.16	0.0051	60.34	60.11	0.0039	50.02	49.89	0.0026
500 MU/min	0.5 cm	93.42	93.09	0.0018	75.91	75.45	0.0031	62.93	62.66	0.0022
	1 cm	93.12	92.86	0.0028	75.53	75.11	0.0057	62.53	62.31	0.0036

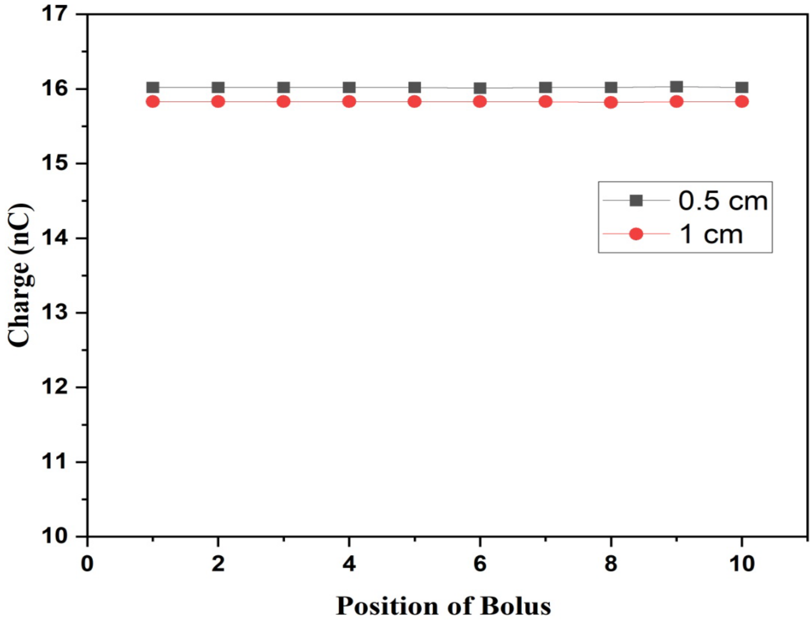

Figure 5. Homogeneity of Silicone Elastomerbolus

Table 4. Mass Attenuation co Efficient (MAQ) of Boluses for Photon energy 6 MV with Radiation area 10 × 10 cm^2 at Different Monitor Unit

Monitor Unit		Without Bolus	With Bolus	MAQ	Without Bolus	With Bolus	MAQ	Without Bolus	With Bolus	MAQ
		Depth 90 cm			Depth 100 cm			Depth 110 cm		
		Dose nC								
100 MU/min	0.5 cm	20.11	19.76	0.009	16.3	16.02	0.0089	13.47	13.23	0.0093
	1 cm	19.89	19.51	0.0199	16.01	15.83	0.0116	13.13	13	0.0102
200 MU/min	0.5 cm	40.36	40.12	0.003	32.86	32.5	0.0057	27.09	26.89	0.0038
	1 cm	40.06	39.99	0.0018	32.46	32.24	0.007	26.83	26.61	0.0085
300 MU/min	0.5 cm	60.41	60.14	0.0023	48.91	48.67	0.0025	40.58	40.33	0.0032
	1 cm	60.17	59.9	0.0046	48.73	48.35	0.008	40.38	40.08	0.0077
400 MU/min	0.5 cm	80.63	80.13	0.0032	65.16	64.86	0.0023	54.03	53.78	0.0024
	1 cm	80.34	79.91	0.0055	64.91	64.51	0.0063	53.81	53.49	0.0061
500 MU/min	0.5 cm	100.4	100.1	0.0015	81.21	80.98	0.0014	67.61	67.26	0.0027
	1 cm	100.09	99.82	0.0027	81	80.63	0.0047	67.37	67.01	0.0055

durability of the bolus is good which is performed over a period of one month. The homogeneity of the bolus is good enough with a standard deviation of 0.0002%. Transmission factor is less than 1 which means that the beam intensity is reduced and mass attenuation coefficient calculations are done which gives the information of increase of attenuation coefficient for thickness 0.5 to 1 cm.The result satisfies the needed value. This proves that the fabricated silicone elastomer based bolus meets all the requirements for a best bolus along with the advantages of transparency, nontoxic and in addition its completely elastic and flexible which can fold in full 360º and when placed in skin it completely fills the uneven surfaces by falsely sticking to it. But it also has limitations on cost effectiveness for the material silicon elastomer and its manufacturing procedure has to have a dedicated setup to maintain pressure and other specificities.

Author Contribution Statement

All the authors contributed equally in the submitted work.

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Conflict of interest

No Conflict of interest.

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